

STRATIGRAPHY AND STRUCTURE OF THE CALVERT FORMATION IN SOUTHERN MARYLAND

A DISSERTATION

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STRUCTURE OF THE COASTAL PLAIN OF SOUTHERN MARYLAND.

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ABSTRACT.

In this paper it is shown that the formations of the Coastal Plain of Southern Maryland do not possess a simple dip to the southeast (seaward), but that they have been warped into an open anticlinal structure, whose form is given by tentative structure contours.

Reasons are given for believing that the movement took place largely in Pleistocene or post-Pleistocene time. The bearing of the warping on distribution and thickness of Miocene formations, present topography, neighboring structures, and on the "terrace problem" is presented briefly.

INTRODUCTION.

For several years the writer has been accumulating data which show warping of the Coastal Plain of Southern Maryland.¹ The collecting of this information is by no means complete, but since resumption of work in that area seems unlikely, the results are presented at this time. The existence of the warping itself is of intrinsic interest, as are also the methods of establishing it. Moreover, in the pages which follow it will be found that the facts which prove warping suffice to resolve a number of other problems of the Coastal Plain.

The elevations—the important data of this paper—were obtained by the use of a Paulin altimeter. Checks with points determined by precise leveling were made at least once an hour,—generally at smaller intervals, so that the readings of altitude surely offer quite negligible errors compared with those made in estimating thicknesses, in placing key horizons properly in the geologic column, and in interpreting the results obtained.

The paper will be divided into two parts: the first part will contain little more than facts, which are the elevations given

¹ "Southern Maryland" is a local, collective name for the five counties shown in the figures on later pages.



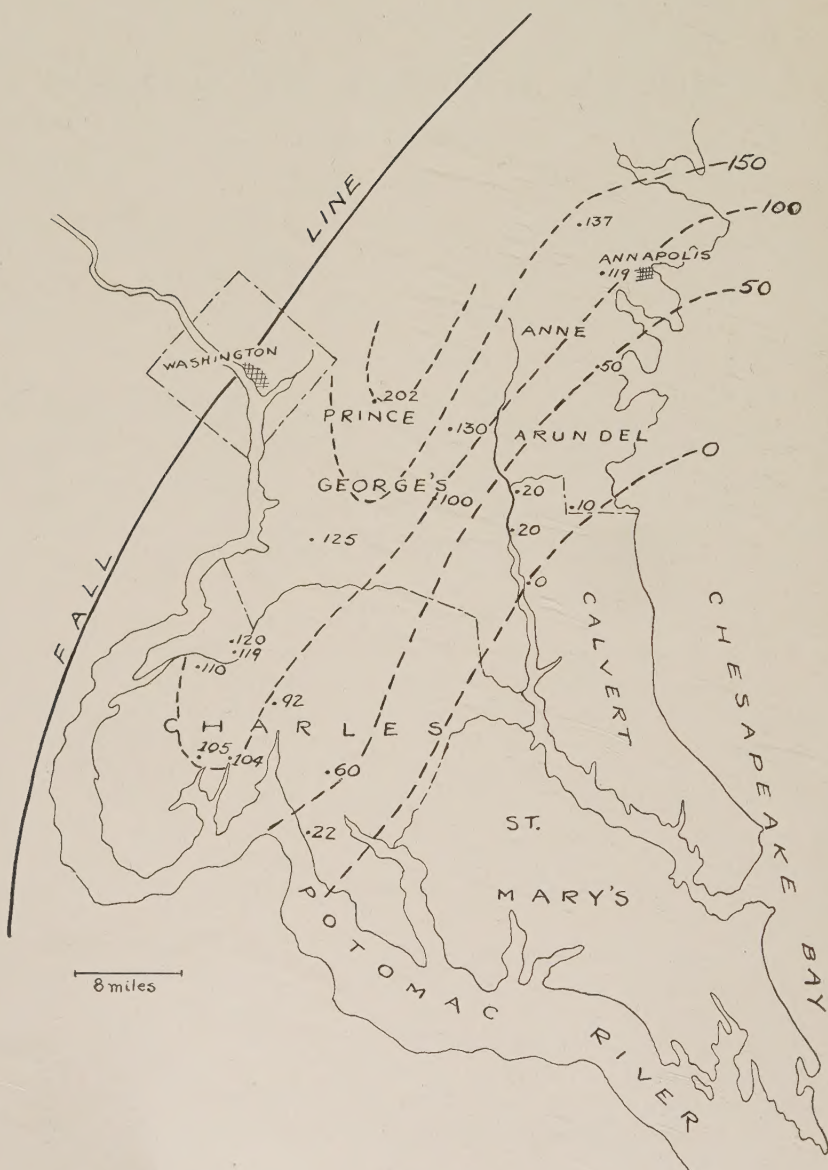


Fig. 1. Elevations and contours on the Eocene-Miocene surface of unconformity.

in figures 1, 3, and 4. The second part will be independent of the first and nothing in it can be used to disprove the facts of the first part.

PART ONE

CONFIGURATION OF THE SURFACE OF UNCONFORMITY BETWEEN THE EOCENE AND MIOCENE FORMATIONS

The simplest picture of the geology of Southern Maryland (such as one gets from the geologic map of Maryland, 1907 or 1933, or from the sketch map, Fig. 2, p. 4, Guidebook 12, 1932) is one of younger formations imbricated with gentle dip successively to the southeast. The lower Cretaceous is found near the fall line; to the southeast and east is the upper Cretaceous, and still farther in the same direction are the two formations of the Eocene (Aquia and Nanjemoy) which crop out near the central and western parts of the region and extend underground to the southeast. The Miocene, next above, covers the Eocene as a generally thin sheet; in places this covering has been removed. In many more it has been cut through by streams and gulleys, which show in their walls the light-colored sands of the Miocene overlying the greensands of the Eocene.

In the publications of the Maryland Geological Survey some half dozen exposures of the Eocene-Miocene contact (between the Nanjemoy and Calvert formations, respectively) are described. Paleontologists have demonstrated the unconformable nature of the contact; for our purposes this relationship is shown by the striking change in lithology and by definite, though generally small scale, signs of an erosional contact. Brownish green to olive green glauconitic sands are everywhere overlain by light buff or whitish sands and clays. There are no exceptions: the top of the greensand is the top of the Eocene, and the sharp change of lithology is of inestimable aid in mapping. The writer has found some twenty additional exposures of this contact in Southern Maryland² and has determined the elevation of the contact at all outcrops. The elevations are the numbers of Fig. 1. (In a few cases two or more readings were so near and so similar that but one has been given in the Figure.) Suggested contours on the

² Those in Charles County will be described in detail in the forthcoming "Geology of Charles County," Maryland Geological Survey (awaiting publication).

Pleistocene	"terrace" sands and gravels		
Miocene	St. Mary's formation		
	Choptank formation		
	Calvert formation	Plum Point marls	
		Fairhaven diatomaceous earth	
Eocene	Nanjemoy formation		
	Aquia formation		

Fig. 2-A. Generalized section of younger formations of Maryland Coastal Plain (following usage of Md. G. S.).

Pleistocene			"terrace" sands and gravels
Miocene	Calvert	upper Calvert, or Plum Point marls	sands and clays of Calvert Cliffs and S.E. margins of area of this work
		lower Calvert (Fairhaven diat. earth of Md.G.S.)	35' fine brownish sand 35' fine whitish sand 10' diatomite 0-100' sand and clay (usually <15')
Eocene	Nanjemoy	greensand	
	Aquia	greensand	

Fig. 2-B. Typical section in area of this work and names used here. Note that upper Calvert is added for completeness only.

surface of unconformity have been drawn in dashed lines, with a contour interval of 50 feet.

It may be objected immediately that these contours can have no bearing on the structure of this area, since they are drawn on a surface of unconformity, not on a bedding plane. Even so, there is something of interest in the fact that this surface does not have the traditional strike and dip supposedly possessed by all the elements of the Coastal Plain. For years the various formations, and tacitly, the surfaces of unconformity between some of them have been thought of as having a northeast-southwest strike and a southeast dip. Measurements of the strike being impossible in single exposures (because of gentle dip), it was assumed that the strike of the beds had the same direction as their general trend across Maryland,—a direction parallel to the fall line of Fig. 1. The surface of unconformity under consideration, however, has reversals of this supposed or "usual" southeast dip, and corresponding changes in direction of strike. In Fig. 1, for example, the 200 and 150 feet contours must bend around somewhat in the manner shown, and there seems little doubt that the 100 feet contour has the same general course.

But other evidence suggests that the configuration of this surface is not the result of erosive processes only. The contours of Fig. 3 (to anticipate somewhat) *are* structure contours (see *infra*) in that they are drawn on a bedding surface in the Miocene, which lies on the unconformable surface. The Miocene, then, has been warped since its deposition, and the surface of unconformity beneath it must have suffered the same movement. The present configuration of this surface is the sum of its original configuration, plus the deformation of Fig. 3, plus, strictly speaking, any other deformation not as yet known by field evidence. If we make certain assumptions about the post-Miocene deformation of Fig. 3 we shall be able, in the second part of this paper, to find out the original topography of the Eocene-Miocene unconformity.

STRUCTURE OF THE MIOCENE BEDS OF SOUTHERN MARYLAND

Considerable difficulty is experienced in finding key horizons in the Miocene of Southern Maryland. This statement may be a surprise to a reader of the Miocene volume (Maryland Geological Survey 1904), since in that volume the Miocene rocks (Calvert, Choptank, and St. Mary's formations) are

divided into a number of what seem to be clearly separable "zones." To convince the reader that some of this simplicity is apparent only, a modicum of information about the Calvert formation, particularly, must be given.

Figure 2-A gives a general section of the younger rocks of the Coastal Plain and shows all the formations of the Miocene found in Maryland. The Calvert formation is divided into two conformable parts. Figure 2-B shows the type of section used in establishing the facts of this paper, and the names used by the writer. A not obvious point is the unconformity found between the two divisions of the Calvert formation.

The writer has used "lower Calvert" in place of the name "Fairhaven diatomaceous earth" introduced by Shattuck, author of the stratigraphic section of the Miocene volume. Justification for the present usage is as follows: a/ the "real" (commercially valuable) diatomaceous earth forms, at a maximum, about one-ninth of the thickness of the Fairhaven diatomaceous earth, and a much more descriptive name would be "Fairhaven sands"; it is not that Shattuck purposely avoided the latter name, because he nowhere mentions the fine-grained sands, and probably did not know of their existence; b/ when one uses the term "diatomaceous earth," several interpretations of the expression are possible: 1/ it may be a short way of saying "Fairhaven diatomaceous earth,"—i.e., all beds lying between the Plum Point marls and the Eocene; 2/ it may be synonymous with "zones" 1, 2, and 3 of the Miocene volume. But it is now known that between "zone" 3 and the Plum Point marls ("zones" 4-15) there are 70 feet of fine-grained sands; 3/ it may refer to "zone" 3,—the commercially valuable diatomaceous earth (in this paper called "diatomite"), whose thickness was grossly exaggerated; or 4/ it may refer to something quite indeterminate. For example, when Shattuck says that the diatomaceous earth at Chesapeake Beach well is 55(?) feet thick, we do not know what he is talking about, because he may be including more than the diatomite, and, in fact, may be talking about something else entirely. The writer is not in the least interested in introducing new names. He is striving only for clarity, and to that end believes that use of the term "lower Calvert" for the beds listed in Fig. 2-B is simpler and less likely to cause confusion in the discussion which follows.

The upper Calvert (this name is used just because it is coördinate with "lower Calvert,"—"Plum Point marls" is

perfectly satisfactory) is well displayed along the Calvert Cliffs, on the Calvert County shore of Chesapeake Bay (Fig. 1). Along this shore some of the "zones" of Shattuck can be differentiated and followed for several miles. There is no difficulty in finding "key horizons," and in seeing that all of them slope to the south. But there *is* difficulty, and grave difficulty, when one tries to follow these horizons back from (to the west of) the Bay shore. So far, not a single one of the "zones" has been recognized anywhere except in the Cliffs themselves. More than that, when we go as far as some fifteen to twenty miles west of the Bay, it can be shown with a great deal of probability that the upper Calvert is missing entirely. Over the whole of Charles, Prince George's and Anne Arundel Counties—the very area with which we are most concerned—we can say that the upper Calvert is absent, or, if present in the very easternmost parts of these Counties, is too poorly known to be used in the present work. And along the Calvert Cliffs the upper Calvert is known in two dimensions only, so there we can say no more than that the "zones" delimited by Shattuck slope without exception to the south.

Over most of Southern Maryland, then, we have but the lower Calvert formation as it is given in Fig. 2-B. And in this lower part only two horizons have been recognized at more than a very few exposures. These two are a/ the top (or bottom) of the diatomite, and b/ the contact between the two fine-grained sands, some 35 feet above the top of the diatomite. Elevations have been taken at a number of points on both these horizons; those on the diatomite have been increased by 35 feet so that all might be plotted, as shown in Fig. 3, as the elevation of the contact between the sands. Chances for small error are, of course, present in the assumption that the distance between these two horizons remains constant; the writer has information which leads him to believe that such errors are negligible. Also, one may make a complete mistake in recognizing the upper horizon (there is little likelihood with the diatomite), and a few readings which failed utterly to fit in with the elevations of Fig. 3 have been left out of the diagram. It should be pointed out, then, that it is not possible to claim absolute validity for any one, or even any few, readings. The conclusions and contouring are based on the agreement of almost all the readings taken in the field, some of which were, at the time, classed as "probably good guesses." Unfortu-

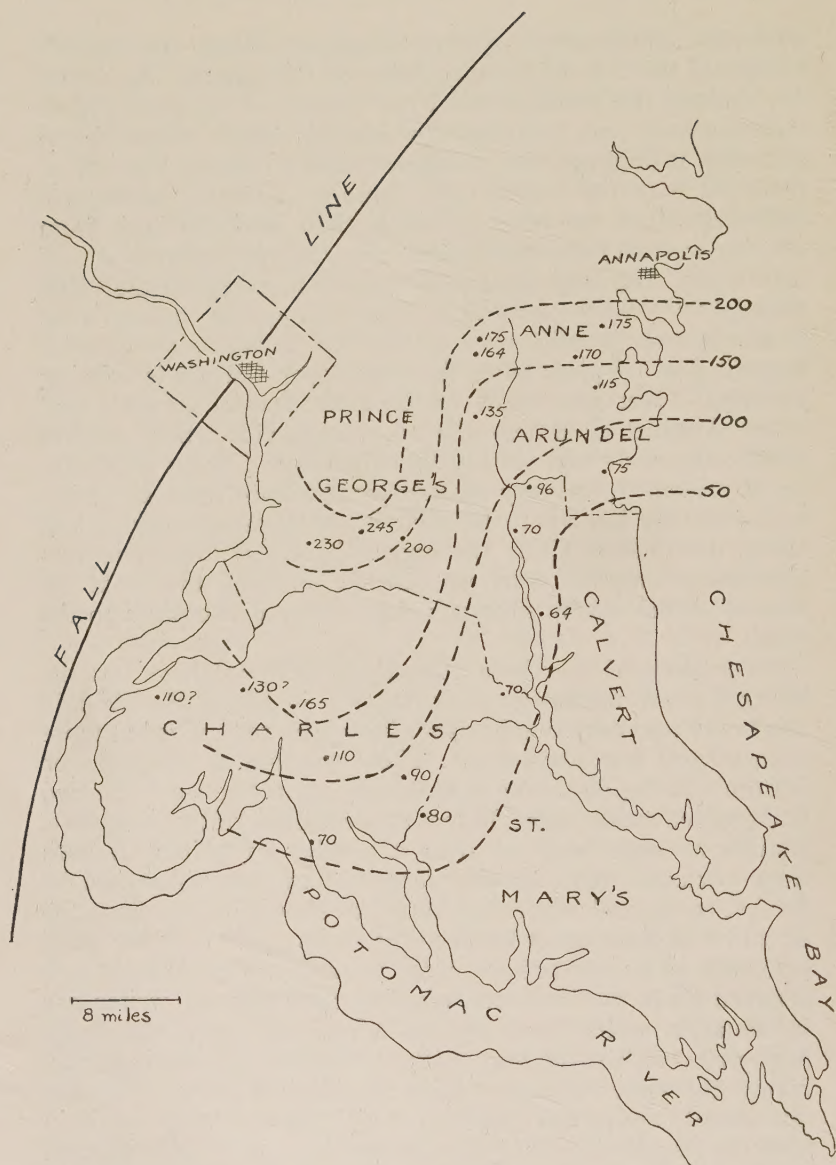


Fig. 3. Elevations and structure contours on Key horizon in the lower Calvert formation (Miocene).

nately, two of the most critical elevations of Fig. 3 (the westernmost two) are not at all definite, but it is believed that the suggested contouring would have been essentially the same without them. Almost all of the field information is summarized in Fig. 3. No great accuracy is claimed for the contours as drawn, although some such course seems called for by the elevations given.

STRUCTURE AND SURFACE-CONFIGURATION OF PLEISTOCENE FORMATIONS

Overlying all older beds in Southern Maryland are a series of gravels, sands, and clays, to which a Pleistocene age has been assigned. Usually these beds are quite thin; the writer has never seen more than 30 feet in one exposure, and that thickness is much greater than average. Ten feet probably would be an average maximum at any one exposure.

These deposits, despite their thinness, stretch for miles. Almost all of the flat or gently sloping areas are covered by them, and it is only in the headwaters of some of the more vigorous streams that we find them stripped away. The State geologic map (1933), for example, shows one apparently unbroken sheet extending for about twenty-five miles north of the center of Charles County.

It seems obvious that such an unbroken, thin sheet, whose upper surface shows not the slightest trace of erosion, must preserve its *original* upper surface. If erosion had acted on it at all, we should expect that somewhere the underlying beds would have appeared from beneath the thin cover. Therefore, the upper surface of most of the Pleistocene deposits represents a bedding surface, and at the same time it forms the present, or topographic, surface. If this be true, the present topographic contours are also structure contours, and they should tell us whether or not the Pleistocene beds have been disturbed since their deposition.

Fig. 4 shows the general course of the 140, 160, 180, 200, 220, 240, 260, and 280 foot contours across Southern Maryland. The figure was constructed by simply laying the topographic maps of the four Counties together and following the contours. Then the geologic maps were examined to be sure that the contours lay on the surface of Pleistocene beds. This was found to be the case with the exception of one area; that area lies in the northeastern part of the figure. It can be



Fig. 4. Structure-topographic contours on the present (bedding) surface of Pleistocene formations.

seen easily on the geologic map of the State, which shows an area of some 100 square miles in Prince George's and Anne Arundel Counties from which the Pleistocene cover has been removed. This fact explains the bunching of contours (here dotted) in the upper right of our figure. In this region we are *not* dealing with original, or bedding, surfaces. If the Pleistocene beds had not been destroyed there is no doubt that the contours would have taken courses more to the west, and would not have bunched themselves around a Pleistocene outlier (Marriott's Hill) in Anne Arundel County. The north-eastern part of this figure, then, should be disregarded, both in reference to other parts of the same figure, and in reference to Figs. 1 and 3.

The rest of Fig. 4 is more than sufficient to be of interest. Comparison with Fig. 3 shows a striking similarity of contour trends,—all the more striking when it is said that Fig. 3 was drawn before even the idea behind Fig. 4 was conceived. But a consideration of the meaning of the facts summarized in Figs. 1, 3 and 4 will be reserved for the second part of this paper.

PART TWO

In this section of the paper connected exposition is not possible. The bearing of the facts of Part One will be considered with respect to several problems; these various problems may show no relationship one to the other, except as they are related to the facts treated in this paper.

RELATIONSHIP OF THE CONFIGURATIONS OF FIGURES 1 AND 3

A comparison of Figs. 1 and 3 shows that the present topography of the Eocene-Miocene surface of unconformity differs in its configuration from that of key horizons within the Miocene Calvert formation. It has been previously said that the contours of Fig. 1 are not structure contours,—at least could not be called such from the information presented in that figure. Those of Fig. 3, however, were derived from elevations of bedding surfaces in the Miocene and are, therefore, structure contours. They show that the Miocene key horizons must have been deformed since their deposition, and that, therefore, the Eocene-Miocene surface of unconformity must have suffered the same movement. The configuration of the latter diagram, then, must be a resultant of at least two

things,—its initial configuration, plus the movement shown by the contours of Fig. 3. If we can be sure that the key horizons of Fig. 3 were horizontal at the time of deposition we can find out the relative importance of these two contributions to the configuration of Fig. 1. And first we must be sure that the key horizons were not deposited in their present position, with their present "structure."

Difficulties in the determination of initial dips, except in the most favorable circumstances, seem insurmountable. It appears to the writer virtually impossible to prove that any sedimentary unit was laid down in a horizontal plane. Brown,¹ in a recent article, after pointing out that any sandstone could have been deposited on a slope of as much as 555 feet per mile, says that "it is improbable that any marine sandstone has been deposited with an initial dip of such magnitude, but this possible value is so great that probably very few marine sandstones or shales have been formed without an initial dip worthy of careful consideration. Hence, in all of the following discussion, observed dips are treated as initial unless conclusive contrary evidence is present." It is believed that such a method of work cannot be consistently followed. There is nothing theoretically wrong with it, but in practice unbelievable hardship would be entailed.

A common sense view of the problem would consider the vast amount of demonstrably correct structural work done without a thought of initial dips. Sandstones and other clastic sediments have been mapped, structures determined by the ordinary methods, and then proved by drilling. In thousands of cases such work has shown itself to be correct. Arkell,² quoting from Lamplugh, has given the principle followed by most of us: "When a particular bed in a stratified sequence bears evidence of having been deposited at the same depth, and at about the same time, over a wide area, it marks a plane originally parallel to the sea-level of its period—i.e., a plane of horizontality. When several beds of this kind occur at intervals in the sequence and are not parallel to each other, we must infer that there has been relative change in the local plane of horizontality during the accumulation of the sequence, and we are enabled to determine the direction and amount of the change." This principle, generally employed in a tacit manner, does not by any means deny that there may be many cases in which initial dips are of importance. It does, however, put the burden of proof where it more properly

belongs,—on the person who would convince us that a very large number of wide-spread, fine-grained sediments were deposited with a significant initial dip.

The diatomite of the lower Calvert formation has been followed from the shore of Chesapeake Bay for some thirty miles across Southern Maryland into Virginia; in the latter State it seems to extend without interruption at least as far as Richmond. Across the strike it has been traced more than fifteen miles in Maryland, until it disappears below tide to the east, or, reaching the tops of the hills to the west, is destroyed by erosion. This horizon would seem to meet the requirements set forth by Lamplugh. It is marine, thin, extensive, and probably all of the same age. Moreover, contours drawn on the bedding surface of the diatomite and on the overlying fine-grained sand agree closely in trend with those on bedding surfaces of the unconformably overlying Pleistocene; this agreement suggests strongly that both were laid down in a horizontal plane and subsequently warped in the same movement.

At least three possible explanations of this agreement in trend are evident: a/ that the Pleistocene beds were themselves laid down with the same initial dip as the Miocene beds might have possessed. In this case, however, it is difficult to see how the Pleistocene could have had the same dip, since a long period of erosion intervened. This erosion would have truncated the Miocene beds, and the Pleistocene sands and gravels would have been deposited across the beveled edges. The structure contours of Figs. 1 and 3, however, show that the beds are parallel,—the inference being that Miocene was still horizontal when the overlying beds were deposited; b/ that the contours of Fig. 4 are on the surfaces of almost horizontal terraces, and that there are no dips (or inconsiderable ones only), the changes in elevation being made over scarps or rises. This possibility will be treated at some length in considering dating of movement. It is in any case not an explanation of the agreement in trend; c/ that both the Miocene and Pleistocene beds have been warped in the same, i.e., post-Pleistocene, movement. This explanation, only, seems cogent.

For these reasons it is assumed that the diatomite and overlying fine-grained sands were deposited without significant initial dip,—that the contours of Fig. 3 represent deformation or warping subsequent to deposition. Proceeding on this assumption we can evaluate the importance of initial configuration versus warping of Fig. 3 in giving the present configuration to the surface of unconformity of Fig. 1.

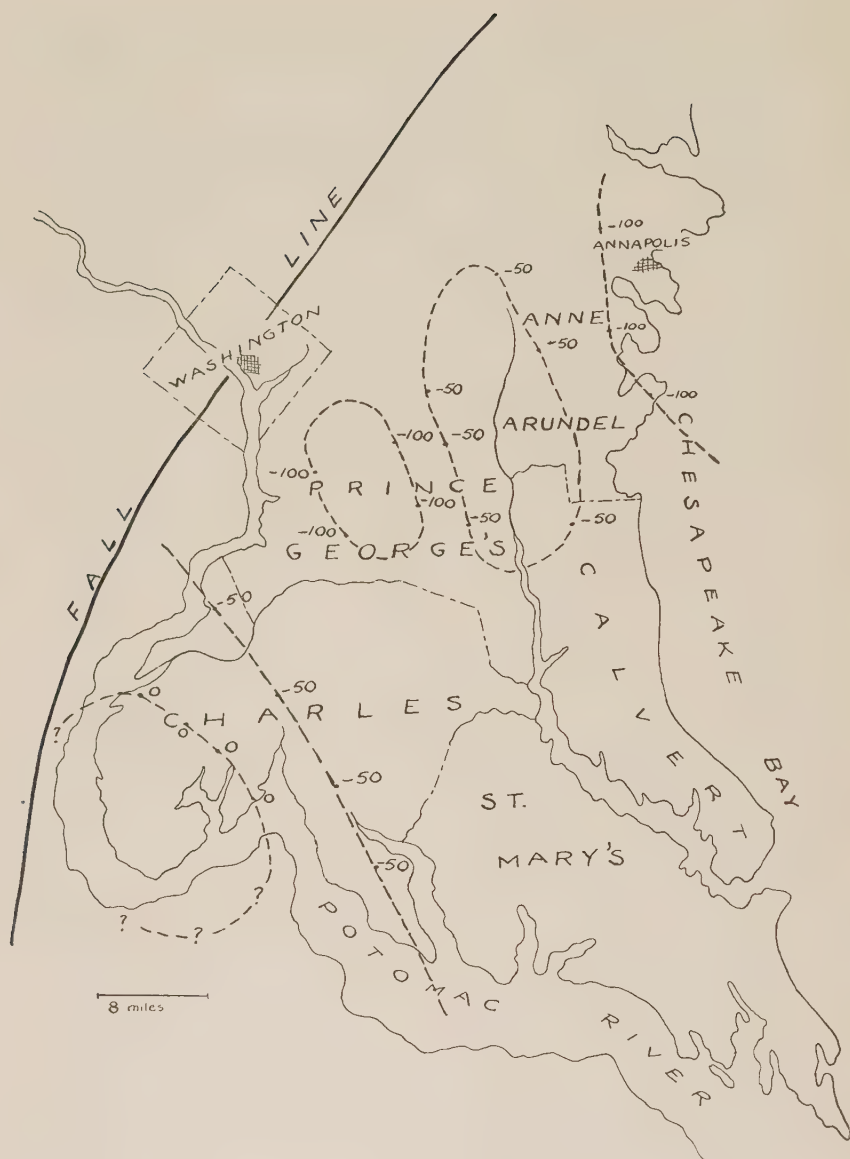


Fig. 5. Configuration of Eocene-Miocene surface of unconformity during deposition of key horizon of Fig. 3.

We can annul the effect of warping of Fig. 3 by superposing Figs. 1 and 3, and then restoring all points of the key horizon of Fig. 3 to sea-level. Wherever a contour of Fig. 3 crosses one of Fig. 1, the elevation of the former is subtracted from that of the latter. Thus, if a 200 foot contour of Fig. 3 crosses a 50 foot contour of Fig. 1, we subtract 200 from 50; from this operation emerges the fact that the point of intersection must have been 150 feet below sea-level (—150 feet) before the warping of Fig. 3. (For details of this method consult Arkell.³) Calculations for all points of intersection will give us the elevation of a number of points on the surface of unconformity *at the time of deposition of the key horizon in the lower Calvert formation*. Fig. 5 shows the character of the surface at that time. If we neglect, or regard as small in amount, any movement which might have taken place during the deposition of the Miocene beds below the diatomite, then we can say that the erosion surface on the Eocene presented at the beginning of Miocene sedimentation a rather featureless sort of plain (Fig. 5) with a slightly deeper part (or depression) about 100 feet below water in the northeast, an elliptical depression of the same depth near the center of our area, and an island or shoal reaching just about to sea-level in the southwest. (The relative elevations, only, are important. All may be lowered by an unknown, but probably not very large figure.) Deposition proceeded in such a way that the hollows or depressions were filled first; they thereby received a greater thickness of sediments. After some 50 feet had accumulated over the greater part of the area (and 100 feet in the depressions) conditions changed in some unknown way to bring about the deposition of diatomite, which was laid down on a smooth, horizontal surface of the underlying beds. In a similar manner, the fine-grained sands were deposited, bringing to a close, so far as is known, Miocene sedimentation in this area.

But do we find a different thickness of the lowest Miocene beds in different places,—more specifically a 50 foot greater thickness in the depressions, and a smaller than usual thickness over the ancient topographic high? So far as information is available we do. The writer knows little about the lowest beds in the northeastern area; in the central “depression,” however, he had been for some time puzzled at a thickness greater than usual, and at the appearance of beds which did not seem to fit into the column as known elsewhere. Measure-

ments in this region showed that the stratigraphic interval between the key horizon and the surface of unconformity is at least 100 feet,—about twice its usual amount. In the southwestern area, search was made in vain for the diatomite, and its “anomalous” absence found no explanation before the facts of Figs. 1 and 3 were compared and synthesized. Fig. 5 shows that no more than the very upper part of the lower Calvert formation should have been deposited over the topographic high, and while the writer cannot be sure that the beds present *are* at that horizon, it *is* certain that the Miocene in this area is very thin,—in some places not more than five or ten feet, and entirely absent in others. Thus the known facts of thickness and distribution support the correctness of the stratigraphic interpretations and elevation determinations of Figs. 1 and 3, and give credibility to Fig. 5 as a representation of the Eocene-Miocene surface of unconformity at the time when the key horizon was laid down. Perhaps this surface had about the same configuration at the beginning of Miocene sedimentation.

From Fig. 5 the reader can judge the relative importance of the two contributions to the present configuration shown in Fig. 1: a/ the initial configuration, Fig. 5; b/ the warping of Fig. 3. Certainly the warping changed the appearance of the topography of Fig. 5; from a surface largely without trend or grain there was formed (Fig. 1) a definite elongate structure whose direction approximates that of the fall line.

RELATION TO NEARBY STRUCTURES AND REVERSALS OF DIP

Campbell⁴ has recently described Pleistocene or post-Pleistocene warping in the Piedmont region of Pennsylvania and Maryland. The axis of his structure—the Westminster anticline—passes but a few miles west of Washington, and is there almost parallel to the structure of Figs. 1, 3, and 4.

Darton⁵ has found evidence for “some flexing and faulting” near the fall line in Maryland.

Clark,⁶ studying the Cretaceous beds of Maryland and Virginia, spoke several times of the “anomalous position” of the rocks at certain localities. He sought to explain the unexpected elevations by recourse to faulting, though he never adduced evidence to support this hypothesis. One of his localities, Catonsville, near Baltimore, lies on a prolongation of the structure described in this paper. It is thought likely that

some of his other "anomalies" can be explained by the warping of Fig. 3 or by similar warpings elsewhere in the Coastal Plain.

The writer has done no field work in Virginia along the axis of warping. However, he has used the information in "Physiography and Geology of the Virginia Coastal Plain" (Va. G. S., 1912) in an attempt to trace its continuation. A plot of elevations of the Eocene-Miocene contact in the Mattaponi River valley (pp.110-114) shows a reversal of dip not far from the fall line. Whether this is a continuation of the warping is problematical, since there are so few readings in the southwestern part of Fig. 3. The axis of warping seems to be directed more closely toward another reversal of dip,—that found in the Nomini Cliffs, Potomac River. Another reversal near Yorktown, Virginia,—first called to my attention by Doctor L. W. Stephenson—probably does not lie along the axis,—though this is but a personal opinion.

It is believed that work along the Rappahannock River in Virginia would give the trend of the warping found in the Mattaponi Valley, and would show whether or not this was the continuation of the structure found in Maryland. Considerable interest is attached to the problem of relating various reversals of dip in this part of the Coastal Plain.

RELATION OF WARPING TO DISTRIBUTION OF MIOCENE FORMATIONS

It has already been suggested, and it will be reiterated later, that the greater part of the movement described in this paper took place in Pleistocene or post-Pleistocene time. At one exposure, however, a slight angular discordance shows that some movement took place between the Eocene and the lowest Miocene, and there is no reason for assuming that there was *no* movement during Miocene time. Indeed, the strata of the upper Calvert formation along the Bay cliffs show a greater slope of older beds than of younger.

But whatever the facts at hand, a simple relation between warping and distribution can be postulated: the northern and western limits of the lower Calvert formation may be thought of as forming a broad curve through Annapolis, Washington, and then south more or less along the fall line. The upper Calvert and the Choptank formation have as their limits a curve essentially parallel to the first, but at least twenty miles

east and southeast of it. The still younger St. Mary's formation lies still farther to the south and east, and the Yorktown formation above is not exposed as far north as Maryland.

Such a distribution could have been brought about by even a slight continuous warping during Miocene time. As upwarping progressed to the north and west, sedimentation was limited in that direction, and later beds were restricted more and more to the east and south. Along the famous Calvert Cliffs, which stretch almost the entire Bay length of Calvert County, the beds show a regional southern slope. The structure contours of Fig. 3 show that there has been considerable uplift of the region just to the north of the Cliffs. This uplift would suffice to explain the origin of the southern slope.

DATING THE WARPING, AND ITS BEARING ON THE ORIGIN OF THE PLEISTOCENE "TERRACES"

Of great interest is the question whether the greater part of the warping took place before or after the formation of the Pleistocene deposits. An answer could be given immediately if one knew key horizons in those sand and gravel beds which cover so much of the Coastal Plain. However, not only do we *not* know such horizons, but there is no way of telling where one "formation" ends and the next begins,—a confusion clearly shown in the following differences of opinion:

Cooke⁷ believes that the Pleistocene deposits of the Atlantic Coastal Plain were laid down, and still are preserved as, sea terraces. Each terrace slopes slightly and gradually to the east or southeast until it is bordered in that direction by a sea cut cliff, or scarp, over which a small but rapid descent is made to the next younger terrace. The height of high-water at the time of formation of each scarp is given by Cooke, who believes that this height for the same scarp is the same along the whole Atlantic Coast,—and indeed on other coasts. He is forced to assume, of course, that there has been no warping or differential movements of the land since the formation of these terraces, otherwise the same scarp would have different elevations in different localities. According to Cooke the highest land in Southern Maryland is part of the oldest terrace, and around that highest part are a series of successively lower and younger terraces.

Campbell⁸ does not believe that the deposits over 100 feet in present elevation were formed by the sea. He thinks that they

were laid down by the Potomac River in an alluvial fan. The present higher parts of the Pleistocene beds are higher because the River flowed at a higher elevation in Pleistocene time. It deposited its load of sand and gravel on a surface sloping to the south and east, so that a bed now at an elevation of 300 feet near Washington might have been formed at the same time as one now 150 feet high some ten or twenty miles to the southeast. Campbell is not concerned with subsequent warping or changes of elevation; they would not seriously impair the validity of his hypothesis, as they would, however, that of Cooke.

Cooke pictures the terraces as seaward-facing features cut and filled by the sea during eustatic rises of level. They border the coast at a distance such that the requisite height of land is provided. If one were to approach such ideal terraces from the east he would expect to find a stair-like increase of elevations to the west, and would expect also that the contours (neglecting subsequent erosion) would run roughly parallel to the Coast and to the fall line. In Southern Maryland, however, such a westward traveler would find some local deviation from the predicted state of things. He would see that the highest land in this area is near Washington, and that in all directions except north and northwest lower elevations are found as one travels out from this eminence. And were he to plot the *manner* of decrease of elevation he would reproduce our Fig. 4, which shows graphically what has just been said.

And what is so surprising about Fig. 4 is the complete and unexpected agreement in trend shown by the structure-topographic contours of Fig. 4 and the structure contours of Fig. 3. The axis of warping rises to the north and northwest, and so does the elevation of the land; there seems to be a "flat" in the middle of the structure of Fig. 3, and that flat is repeated between the 240 and 260 foot contours of Fig. 4; both figures show the same general sweep of contours except in the northeastern part, and that disagreement has been explained in Part One.

Since the contours of Fig. 4 are drawn on the original Pleistocene surfaces, we are immediately confronted with the question of whether the Pleistocene beds were laid down at their present elevations, or whether they were laid down at (present) sea-level and then elevated, relatively, to their position today. If we adopt Cooke's view that they were deposited in the sea, and that no warping of the land has taken

place since their formation, we must account for, or at least comment on, the rather odd areal relations of land and water at the time. The first emergent Pleistocene material would have been that included within the 280 foot contour of Fig. 4; next that enclosed by the 260 foot contour would have appeared, and then gradually the "peninsula" outlined by the contours of the figure,—terraces being cut in the land as the sea sank step by step. An arm of the sea would have lain to the east, and one would have stretched up to the northwest, behind the "peninsula." No direct proof can be given that the "terraces" *did not* originate in this way. However, a few comments are called for:

a/ The apparent agreement of structure and topography is remarkable, and is most easily and simply explained by saying that the structure is reflected in the topography.

b/ Even if it be granted that the Pleistocene deposits were formed as, or on, wave-cut terraces, still no explanation is given of how the lower Calvert formation, which *is* marine, came to be warped into its present attitude. Both Cooke and Campbell assume that the Miocene had been somehow raised into position, and that on the Miocene as now found the Pleistocene was deposited after a long period of erosion. Though the student of the Pleistocene may not feel called on to say *how* the Miocene attained its present position, the close agreement of Figs. 3 and 4 shows that the Pleistocene beds do not truncate the Miocene strata, and shifts the burden of explanation to the shoulders of one who denies post-Pleistocene warping.

c/ There is no proof known to the writer that the Pleistocene beds were not laid down at a much lower elevation and warped up into the position now found,—that parts were elevated to some 300 feet or more, and that other parts, outside the area of significant warping, remained essentially at the elevation of deposition. On this scheme, elevation is no criterion of age. The writer has spent considerable time in Charles County looking for possible wave-cut, or at least water-cut, scarps; the highest undoubted example known to him has its base at about 65 feet. He does not state this fact to deny the existence of higher scarps in other regions, having little knowledge thereof. He does, however, question their existence in Charles County and adjacent regions. Therefore, he sees no reason why the warping, which seems to have affected Pleistocene surfaces as low as 140 feet above sea-level, should

not be considered as having taken place, in great part, subsequently to the formation of these surfaces. In terms of Cooke's nomenclature, the warping would be post-Sunderland, or possibly post-Wicomico.

No great difference is made in Campbell's "alluvial fan" theory whether the fan were formed at a lower level and then warped up into its present elevation, or whether it formed at the elevation we now find it. The former supposition is much the simpler, since the Potomac River is not imagined as having ever flowed at an elevation of 300 feet higher than the present one. In addition, there is no necessity for explaining the course of the River over what is now the highest land in that part of the Coastal Plain, when probably other, lower paths were open to it. With these emendations, the "alluvial fan" theory seems better to fit the facts, though the present writer is disposed to accept neither that theory nor the "terrace" one as very satisfying. The facts brought forward in this paper do not, in any strict sense, allow one to decide the correctness of either theory.

SUMMARY

The existence of warping in the Coastal Plain of Southern Maryland has been shown. This fact alone is of considerable interest, since no more than isolated "reversals of dip" have been previously reported.

Of far greater interest, though founded on speculation rather than on fact, is the bearing of this warping on several unresolved problems of the Coastal Plain. Guesses have been made of the solution of some of these. As knowledge accumulates it is hoped that something more satisfactory than speculation may be possible.

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THE CALVERT FORMATION IN SOUTHERN MARYLAND

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INTRODUCTION

The Calvert formation (Miocene) of Maryland has been known and studied for more than one hundred years. Attention was early directed to it by the presence of thick fossil beds in the walls of the Calvert Cliffs, along the western shores of Chesapeake Bay. Many papers have been written on the fossils found there, though but few have considered even in a general way the interrelations of the different beds so clearly exposed in the Cliffs. Harris (1) was the first to outline the main structural and stratigraphic details, and to name (or, rather, to letter) some of the prominent beds. Shattuck (2) on the Miocene of Maryland, treated all three of the Miocene formations. He gave much greater detail than had been formerly available, although for the same area—the Calvert Cliffs—he added little to the account given by Harris. The writer has been

interested for several years in the Calvert formation, both in its exposures along the Bay, and in other, less easily studied parts of southern Maryland. He has gathered information showing that some of the older ideas, which have been current for many years, need critical examination, if not revision. In presenting a summary of some recent investigations, the writer assumes the reader's familiarity with the publications cited above.

VALIDITY OF THE "ZONES" OF THE CALVERT FORMATION

Shattuck divided the Calvert formation into fifteen "zones." The lower part of the formation, which he called the "Fairhaven diatomaceous earth," includes the lowest three of these, the upper part, or "Plum Point marls," those "zones" lying above. This classification has great simplicity, but it is faulty in that it leads the reader to expect these units not only at their type section, but in any place where the Calvert is exposed. There are certain reasons why such expectations are not realized.

The three lower "zones" were established in the area of Fairhaven (Fig. 1, locality 1), though only the uppermost one is said to be exposed in the cliffs along the shore of the Bay. Their connection with the upper zones cannot be definitely proved in the field (see below) since there is a hidden area some three to four miles long between localities 1 and 4.

"Zone 1" is described as follows: "At the base of the Calvert formation and lying unconformably on the Eocene deposits is a bed of brownish sand carrying *Phacoides contractus*. This stratum varies somewhat in thickness from place to place, but does not depart widely from six feet on the average." In the publications of the Maryland Geological Survey some half-dozen exposures of the Eocene-Miocene (Calvert) contact are described, and they presumably represent all that was known of that contact. The writer has found about fifteen additional exposures which admit of study of the base of the Calvert formation. In no exposure, either described or new, has anything like Shattuck's "Zone 1" been seen. It cannot be denied that at some place there may be such a layer or "bed of brownish sand—," but the writer has not been able to find it. He has found conditions which vary a great deal from place to place, so that there is no persistent stratum lying just above the Eocene. "Zone 1," then, may be considered non-existent.

"Zone 2" must suffer a like fate. It is described as lying immediately above "Zone 1" and as "a thin stratum of white sand of about one foot in thickness which is locally indurated to sandstone." Such a "zone" has been found in one small area (near locality 2) of southern Maryland. Over nine-tenths of the area known to the writer there is no such indura-

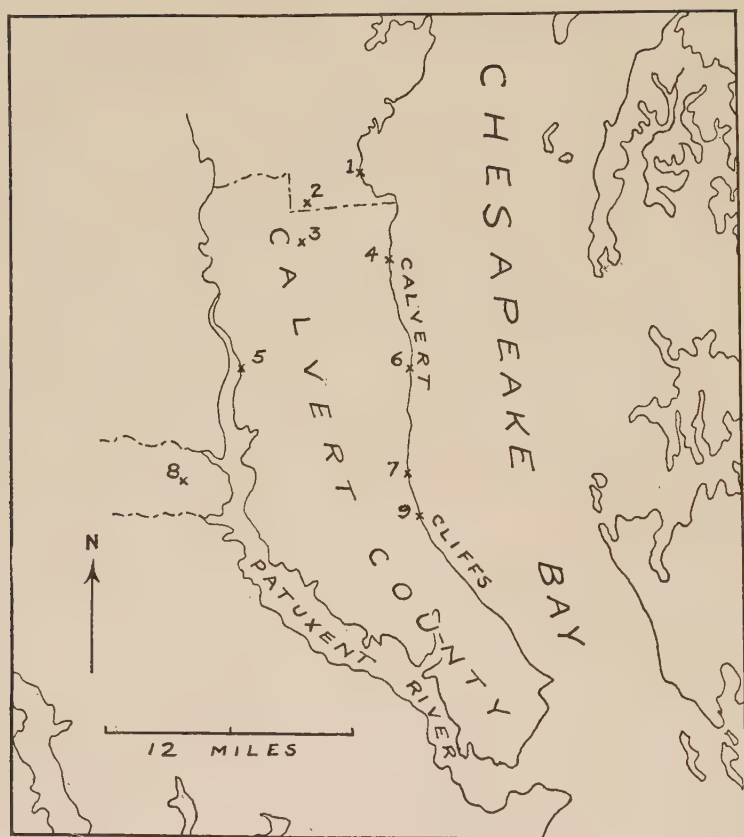


FIG. 1. Localities cited in text: 1—Fairhaven, 2—Pindell, 3—Mt. Harmony, 4—north end of Calvert Cliffs, $\frac{1}{2}$ mile south of Chesapeake Beach, 5—Hollin Cliff, 6—Plumpoint Wharf, 7—Parker Creek Valley, 8—fossil locality in Charles County, 9—Governor Run. For general setting of this map see Dryden (3) or any map of Maryland.

tion about six feet above the Eocene contact. There are, it is true, indurations near the Eocene-Miocene contact, but they are not “bedded” structures, nor do they bear any constant relation to the contact. They may be at the contact, or at variable distances above or below it. Furthermore, the dozen or so species of fossils reported from this zone by Shattuck are almost never found near the base of the Calvert formation. They owe their preservation to the indurations, and when these are absent, so are the fossils.

“Zone 2” was established, it is believed, not only on the evidence from the one small area mentioned (near locality 2), but from the pres-

ence of an indurated bed exposed near locality 5. This indurated bed has not been described specifically in the literature, but there seems little doubt that it was mistaken for the one near the base of the Calvert formation, and was thought of as "Zone 2." Actually, it lies at or near the contact between the upper and lower parts of the Calvert formation, a hundred or so feet above the Eocene contact. On any score, the omission of direct reference to this indurated bed is not understandable in view of the fact that at Hollin Cliff (locality 5), where a section was measured, and where fossils are reported, this bed was not mentioned, although it forms a prominent projection in the cliff face, and large blocks of it strew the shore. If it had been clearly seen at this locality that the indurated bed lay far from the Eocene contact perhaps "Zone 2" would not have been erected.

But little attention will be given here to "Zone 3," since it has been considered elsewhere by the writer (3). It should be said again, however, that the whole "Fairhaven diatomaceous earth" does not consist of diatomaceous material. Indeed, the writer has never seen more than 10 feet of diatomite,—*i.e.*, 10 feet of material which can be, or has been, worked commercially. Most of the lower Calvert in southern Maryland (excluding the District of Columbia and area to the northwest, of which the writer has no knowledge) consists of fine, "fluffy" sands. If the lower Calvert is to be subdivided, more than one "zone" will be necessary.

The upper "zones," numbers 4 to 15, are splendidly exposed along the Calvert Cliffs, from locality 4 on the north, to south of locality 9; and it was in these exposures that they were differentiated. Figure 2 is a diagrammatic cross-section of the northern end of the Cliffs.



FIG. 2. Diagrammatic cross-section of northern end of Calvert Cliffs. Not drawn to scale; vertical scale greatly exaggerated. For localities see Fig. 1.

Both Harris and, later, Shattuck assumed the identity of the lowest bed at locality 4 with the highest bed at Fairhaven (locality 1), this relation being brought about by the southerly slope. Above the lowest bed at locality 4 (top of "zone 3") lies a band of *Ostrea percrassa* a few inches thick ("Zone 4" of Shattuck, "zone a" of Harris) which shows an "anomalous" behavior in that it slopes ("dips") to the north, against the regional slope of all other strata. This unusual slope (wrongly

attributed to the other beds also by Harris) was not explained. A consideration of figure 2 will show that there is no anomaly to be explained.

The top of the lowest bed (or "unit") is plainly a surface of unconformity. Shattuck divided the Calvert formation into two parts, the top of this unit being the top of the lower part (Fairhaven diatomaceous earth). It is not clear why he did not seek for some physical reason for this division, which was apparently (though little more than tacitly) founded on paleontologic evidence. The nature of the contact gives plenty of reason for division: (a) it rises against the regional dip,—this in itself being a good indication of unconformity; (b) the top of the lower unit is bored, pitted, and eroded (4); (c) there is a sharp change in mechanical and heavy mineral composition across the contact (4); (d) the uppermost beds at Fairhaven would, on estimated slope, appear approximately at tide at the locality in question; and (e) the overlying bed conforms to the shape of the surface of unconformity. The lower bed or unit, then, represents an ancient surface of erosion, on which a colony of oysters established themselves; since the surface sloped (and slopes) to the north, the bed of oysters does the same,—there is nothing anomalous about its position. Whether the north slope is still the same *in amount* as it was originally is a question bound up with the origin of the regional slope of the overlying beds,—whether their slope is mainly depositional or due to tilting.

The contact between the two parts of the Calvert formation is not surely known elsewhere, for the reason that neither the top of the Fairhaven beds nor the bottom of the Plum Point marls is recognizable without doubt in any place other than the northern end of the Cliffs. It is thought, however, that the contact should be found at Hollin Cliff (locality 5), where the lower bed is almost surely present, and where perhaps the bed lying above the contact is "zone 10" of Shattuck. This point will be discussed more fully in considering the distribution of the Plum Point marls.

Lying above the unconformity just discussed, and at the base of the Plum Point marls, is a series of olive-green sands and sandy clays. At the north end of the Cliffs they are about 35 feet thick; they diminish in thickness to 7 feet at the last exposure of the unconformity, some $4\frac{1}{2}$ miles to the south. In figure 2 this material is labelled collectively bed I. Shattuck divided it into five zones above the *Ostrea* bed, differentiating the several zones solely on the presence or absence, scarcity or abundance, of *Corbula elevata*, a small pelecypod.

The propriety of such division is questionable: (a) the general concept of a zone established paleontologically is a bed or series of beds charac-

terized by the presence of one or more species of fossils which are either absent or rare in the rock above and below. Shattuck describes "Zone 5" as made up of "greenish sandy clay, which carries scattered bands of *Corbula elevata*." This definition might serve to distinguish it from "Zone 6," which "consists of a greenish sandy clay carrying large numbers of *Corbula elevata*, which are distributed thickly throughout the stratum—," but it will not serve to differentiate it from "Zone 7," which is described in phrases identical with those quoted for "Zone 5,"—in fact the character of "Zone 7" is noted as "resembling very much in appearance Zone 5"; (b) more important, perhaps, are a number of practical objections to Shattuck's zoning: 1. the writer has in certain places been unable to find or differentiate the zones described; 2. in other places it is found that what seem to be the "zones" wedge out and disappear in a short distance, so that they cannot be followed along the Cliffs for more than an unimportant distance. For example, the writer has been able to follow but one single "unit" along the Cliffs for almost the whole exposure of bed I. This is a thin clay bed, often no more than 6 inches in thickness. It lies at an elevation of $19\frac{1}{2}$ feet at locality 4 and can be traced for about $3\frac{1}{2}$ miles to the south, where it lies at an elevation of 4 feet. Careful work may show that some of the *Corbula* "zones" have a continuous extent of this sort, but this has not been demonstrated. (The *Ostrea* band, "Zone 4," which properly should be included within bed I, can be followed for a little less than $1\frac{1}{2}$ miles from the north end of the Cliffs.) This fact indicates that the "zones" have little value for correlation; 3. a study of the mechanical and mineralogical composition of the sediments of bed I shows that no separation can be made on that score. This agrees with what one would expect from the appearance of these sediments in the field,—their lense-like character, minor cross-bedding in a few places, and their rapid alternations of sandy and clayey material point to a probable mixing of sediments of different mechanical, if not mineralogic, composition. From the rather small number of samples examined with this point in mind, there seems to be little relation between even the presence of *Corbula elevata* and character of the enclosing sediment, though it may be that there are more of these fossils in the browner, more sandy layers.

The only exception to the statements made above is offered by the lowest foot or two of bed I. All along the exposures (some $4\frac{1}{2}$ miles) this material has almost the same lithologic characters,—the graphs of composition are markedly similar, and differ a significant amount from those of the overlying part of the bed. It may be that the sediments first deposited on the underwater shoal (surface of unconformity) came

at the beginning all from the same source, or that they were sifted about enough to grade them somewhat (the maximum contains about 40–45% on the $\frac{1}{16}$ mm. sieve, the next to the maximum about 25% on the $\frac{1}{8}$ mm. sieve). It was under these uniform conditions that the oyster bed was formed, and nowhere in the upper part of the bed are more than a few *Ostrea* found.

It is believed that sufficient evidence has been given to justify the grouping of “Zones 4, 5, 6, 7, 8, and 9” under one single bed or unit. This bed was laid down on an unconformable surface, to the outline of which, paradoxically speaking, it conforms. The thin clay seam about in the middle of the bed has the same slope as the top of bed I and immediately overlying beds. The bottom of the bed, however, rises to the south, so that in that direction the bed thins. Whether it wedges out underground is a question not easily answered, since it depends on the configuration of the surface of unconformity,—a quantity which cannot be predicted with confidence. If the oyster bed be regarded as contemporaneous throughout, then sedimentation was faster to the north when the lower part of bed I was deposited, so that the bed might be expected to thin to the south. All the other beds seem to thicken slightly in that direction. Some evidence will be presented later to indicate the absence of bed I not many miles to the west of the Calvert Cliffs (locality 5).

Some of the upper “zones” of Shattuck can be found along the Calvert Cliffs,—although there seems too little reason for calling them by that name. “Zone 10” is plainly the thick sandy fossil bed which lies from 36 to 42 feet above tide at the north end of the Cliffs, disappearing a little more than $1\frac{1}{2}$ miles below old Plumpoint wharf (locality 6). “Zones 11, 12, and 13” are the two prominent clay beds separated by a thin bed which has yielded so many vertebrate remains. This thin bed, which is never more than $2\frac{1}{2}$ feet thick, lies from 46 to 48 feet above tide at locality 4 and disappears beneath tide approximately one-half mile south of the south side of Parker Creek valley (locality 7). “Zones 14 and 15” are believed to have been founded on insufficient evidence, although the writer has not a great many ready facts to support this statement. The higher beds are hard to study along the Cliffs, especially in the northern part. As one passes to the south there is an uncertain correlation, and the writer believes that Shattuck called the same material at one time “Zone 15” (Calvert) and at another time a part of the overlying Choptank formation (see below for this formation). At this time, then, the writer is able only to call attention to possible errors in the earlier work.

DISTRIBUTION OF THE CALVERT FORMATION

The two parts of the Calvert formation—lower and upper, or Fairhaven diatomaceous earth and Plum Point marls—show very different areal extent. The lower Calvert is widespread in southern Maryland, so that its limits may be taken roughly as the limits of the Calvert formation itself (3).

The Plum Point marls are not known definitely in any place other than the Calvert Cliffs. Shattuck stated that they were to be found on Patuxent River, and in the Nomini Cliffs on the Potomac (about 25 miles southwest of locality 9). Neither of these statements has had subsequent verification,—though neither has had direct refutation. The writer can offer nothing decisive in this matter. He does believe that these beds, if present, must be much reduced in thickness, since he has seen no sure sign of them in his cursory examinations along those rivers, with one exception:

Hollin Cliff (locality 5) offers probably the finest section of the lower Calvert formation in the State. From the level of Patuxent River to 52 feet above, the beds resemble those of the lower Calvert as displayed elsewhere. At the top is an indurated bed about 1 foot thick, which probably is the same bed found within a radius of 4 or 5 miles of Hollin Cliff. Overlying the indurated bed is a series of sands exposed for about 20 feet. A layer of *Ostrea percrassa* lies $2\frac{1}{2}$ feet above the base of these sands, then comes 2 feet of broken shells, and then $1\frac{1}{2}$ feet of very fossiliferous sand.

It is suggested that the *Ostrea* bed may be the same as the one at the base of the Plum Point marls on the Bay shore (locality 4), and that the overlying fossiliferous sands may correspond to "Zone 10." (In this case bed I would be missing from this section.) A very fossiliferous layer like this one has been found some six miles southwest of Hollin Cliff, in Charles County (locality 8). Since few or no fossils have been found in the lower Calvert of that county, it is assumed that this layer belongs to the Plum Point marls, and, probably, to "Zone 10." If this be the case—and further work should make it definite—then the Plum Point marls may be shown to extend, in this latitude, at least 10 to 15 miles back from the Calvert Cliffs section.

RELATION OF THE CALVERT AND CHOPTANK FORMATIONS

In the Miocene deposits of Maryland three formations—Calvert, Choptank, and St. Mary's, from oldest to youngest—are differentiated. The Calvert and Choptank are said to be unconformable. The evidence given is both stratigraphic and paleontologic. For example, Shattuck

says that "The best place to observe the unconformity is in that portion of the Calvert Cliffs just below the mouth of Parker Creek [locality 7]. Even here, the unconformity cannot be seen while standing on the beach, but may be observed from a boat a short distance from the shore." Additional proof is that "—the fossil bed which lies lowest in the Choptank formation rests on the Calvert, while at Mt. Harmony [locality 3] and northward the upper fossil bed of the Choptank rests on the Calvert formation. There are also certain differences between the fauna of the Calvert and that of the Choptank."

No one of these statements should be accepted without verification. The writer has been out in a boat at the place mentioned, and has been unable to see the unconformity. Furthermore, he has constructed a large scale cross-section of the stratigraphy of the Cliffs in that vicinity. In this cross-section he at first thought that certain of the beds of the Calvert were truncated by beds lying above,—which would be good evidence for the relation claimed. It has been found in later study that there is no truncation,—that in the region from $\frac{3}{4}$ mile to about $2\frac{1}{2}$ miles north of Governor Run (locality 9) there is a "sag" or depression of all the strata, but that the upper beds do not lie on an erosion surface on the lower. It is believed that there is no stratigraphic evidence in the Cliffs to prove unconformity.

The two other lines of evidence quoted above are disparate in value. That of different beds of the Choptank lying on the Calvert formation need not be considered until exact localities are given, and until one can be sure that he can recognize the same bed of the Choptank formation in different places back from the Bay shore,—something that has not as yet been demonstrated.

That there may be differences between the faunas of the two "formations" cannot be disputed by the writer. Some have claimed that the faunas are quite similar, and that they may represent animals living under slightly different environmental conditions (5). In this case, and in the absence of any definite stratigraphic proof to the contrary, there seems no need to separate the Choptank from the Plum Point marls of the Calvert formation. The Choptank has just about the same distribution as the Plum Point marls. The more important break seems to be that between the lower Calvert (Fairhaven diatomaceous earth) and the Plum Point marls, and the formational boundary apparently should be drawn at that horizon.

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VITA

Lincoln Dryden was born in Baltimore, Maryland, on December 30, 1903. His early training was received largely in the graded schools of Baltimore, and the Baltimore City College. He entered the Johns Hopkins University in 1921, and was granted the degree of Bachelor of Arts in 1925. In the latter year he entered the Department of Geology at the same University. The summer of 1927 was spent as geologist with the Maryland Geological Survey in mapping and writing a report on the geology of Charles County, Maryland. The period from February, 1928, to January, 1929, was spent as assistant geologist with the Sinclair Exploration Company in the State of Zamora, Venezuela. The summer of 1929 was devoted to field work in the Miocene of Maryland, under the auspices of the Maryland Geological Survey.

